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Evaluation of the Influence of Three Types of Light Curing Systems On Temperature Rise, Depth of Cure and Degree of Conversion of Three Resin Based Composites (An *In vitro* study)

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Abstract

Aim of study: The purpose of this study was to evaluate the effect of Quartz tungsten halogen, Light emitted diode & soft start light curing units on temperature rise, depth of cure & degree of conversion of different types of dental composites (Spectrum, Esthet X & Z250).

Methodology: Thirty sound, single–rooted human bicuspids extracted for orthodontic purpose were used to measure the temperature rise inside the pulp chamber by using a needle probe, connected to thermocouple thermometer through the apical foramen. Ninety specimens of dental composites (Spectrum, Esthet X & Z250) were prepared by using special mold to determine the depth of cure of different light curing modes (Quartz tungsten halogen, Light emitted diode & soft start) by using the scraping method described by ISO standard for polymer –based filling restorative & luting materials. For the assessment of the degree of conversion, eighteen samples of dental composites were tested by the Fourier – transformed infrared spectrometry according to the standard baseline technique of Rueggeberg et al., 1990.

Result and Conclusion: QTH light curing showed the highest temperature rise value, while the soft start gave the lowest values. Soft start light curing revealed the highest depth of cure values, while the QTH showed the lowest values among three curing modes. There were overall statistical significant differences in the depth of cure values among groups of different curing systems & types of dental composites. Soft start light curing system showed the highest degree of conversion and QTH had the lowest values. Esthet X dental composite gave the highest results of the degree of conversion while Z250 showed the lowest values.

Introduction

The composite is a dimensional combination of at least two chemically different materials with a distinct interface separating the components. When properly constructed such a combination of material provides properties that could not be obtained with any of the components acting alone [1]. Dental composites consist of a resin matrix (organic phase), inorganic filler particles (dispersed phase), filler matrix coupling agent (interface) and minor additions including polymerization initiators, stabilizers, coloring pigments, and polymerization inhibitors [2].

The setting reaction of composite resin is a polymerization reaction and may be chemically or photo activated [3]. The most common photo absorbing compound used in dental restorative materials is camphorqinone (CQ). The structure of this molecule is such that it characteristically absorbs energy within the blue region of the visible spectrum: from 450 nm to 500 nm, with a peak about 465 nm. Composite based resins can be classified according to their particle size into macrofilled (10 µm - 100 µm); midsize filled (1 µm -10 µm); (0.1 µm -1 µm); microfilled (less than 0.1 µm) [4].

The dentist has to select a light source from a variety of instruments, each based on different premises, the choice is between halogen, Plasma Arc, laser, or LED lamps, with energy level that range from 350 to far above 1000 mW/cm^2 [5].

Light curing units used for polymerizing restorative resins produce heat during operation. The emitted radiation at the light curing tip is mainly visible light and infrared energy; certain curing lights can impart a significant thermal rise, owing simply to the absorbed photon energy. The temperature rise associated with application of intense visible light has been termed the photo thermal reaction. There was no significant difference in the temperature increase in regards of dentin thicknesses [6].

For dental applications, excessive heat must be avoided to protect the dental pulp. Previously they reported that with temperature increases of more than 5.5°C, dental pulp could not reverse inflammation in 40% of subjects tested, an increase of 11°C over normal temperature invariably resulted in necrosis [7].

The hardening of dental composite results from a chemical reaction between dimethacrylate resin monomers that produces a rigid and heavily cross-linked polymer network surrounding the inert filler particles [8]. The extent of this reaction often referred to as the degree of conversion or effectiveness of cure, which is very important in that it dictates many physical and mechanical properties of the composite restoration. The term degree of conversion describes the percentage of double bonds that react during polymerization process [9]. This conversion (monomer to polymer) is dependent on several factors, such as the resin composition, the transmission of the light through the material, the amount of activator-initiator and inhibitor that is present because composites are materials with low thermal conductivity and the effect of energy density on the temperature increase may be dependent on how this energy density is distributed, regarding the time of photo activation and heat dissipation [10].

At the top surface of a photo initiated composite, there is minimal light attenuation; thus, the cure of the top surface proceeds very quickly

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because virtually all CQ is excited ; while, deeper in the composite, light attenuation, as a result of absorption scattering, results in fewer excited CQ molecules, and the probability of a collision with an amine decreases dramatically. This decrement in cure has been termed "depth of cure" [11].

In order to decide how long it takes to adequately cure a composite, one has to look at the energy density used, which is the irradiance of the light multiplied by the time of application (measured in Joules). The distance from the composite surface drastically affects the power generated. The collimation of the light, or how much light is wasted when not focused forward, can drastically affect the power at depth. The wavelengths and the type of composite affect the efficiency of light-curing. The bottom line is that it takes about 17 J/cm^2 to 20 J/cm^2, which equates to 20 seconds with a 1,000-mW/cm^2 light energy to obtain the optimum degree of polymerization of a composite. Independent of the technique being used and the care the clinician takes during the process; insufficient irradiance can lead to inadequate polymerization even after the recommended curing times [11].

The aims of this study were to evaluate the temperature rise in the pulp chamber during polymerization of Z250 composite by using Quartz tungsten halogen (QTH) light cure, Light emitting diode (LED) & Soft start light curing technologies, to evaluate the depth of cure of three types of resin based composites (Spectrum, Esthet X, Z250) and to assess the degree of conversion for these dental composites.

Materials and Methods

Temperature measurement

Sample collection & grouping: Thirty sound, single - rooted human bicuspids for orthodontic treatment were used for this study. The teeth were scaled & polished with pumice & rubber cup to remove all organic debris & stains & stored in distilled water. The samples were divided into three main groups. Each group was composed of ten teeth.

Cavity preparation: Standardized cavities with butt-joint marginal configuration were prepared in the middle third of the buccal & lingual (palatal) surfaces of the tooth (each tooth received two cavities), (2mm high, 3mm wide, 2mm depth) using high speed hand piece which was adapted to the horizontal arm of a surveyor in such a way that the long axis of the bur will be perpendicular to that of the tooth, using a medium grain diamond bur, under water coolant.

To get good standardization & accurate positioning of these cavities, two vertical lines were drawn from the tips of the buccal & lingual cusps to the lowest points of the cervical lines & the mid distance of these lines represent the center of each cavity. The outline of the cavity was drawn on the tooth surface with a 0.5 mechanical pencil using a matrix band with a pre-cut hole of 2 x 3 mm which was fixed on the tooth with a retainer. The cavities per tooth were not interred related, and the data were analyzed as if they were independent replica cavities for each treatment.

Due to the fragility of the thermocouple probe the access through the apex was confirmed by pre-opening the canal through the apex with a root canal reamers from (#20-60) after cutting off the most apical 2-3 mm of the root with a diamond bur to enable access for the thermocouple probe into the root canal.

Filling technique

Each group filled with A2 shade Filtek™ Z250 (3M Espe, America), universal micro hybrid composite, according to its manufacturer instruction. By etching all cavity surfaces for 15 seconds with 37.5% phosphoric acid. The acid etch was removed by thoroughly rinsing by distilled water for 15 seconds and dried lightly. Any lining or bonding agent was not used in this test to exclude the effect of any other material on the thermal conductivity, after that the composite was placed to the cavity by its applicator. It was covered with a celluloid strip. The composite material was light cured so that the distance of light curing tip was in contact with celluloid strip.

Measurement of the temperature rise: The needle probe, connected to K-type thermocouple TP-01, was pushed through the apical foramen into the coronal pulp chamber until resistance was felt the probe remained in place without any special fixing because of the narrowness of the root canal. The exact location of the probe was radio graphically evaluated to insure that its location was within pulp chamber. The temperature inside the pulp chamber was registered before application of the light curing and the temperature rise was registered immediately after applications. The difference between each two registrations was established.

Determination of the depth of cure: To determine the depth of cure a total of ninety specimens were prepared as mentioned previously. The samples were divided into three main groups .Each group was composed of thirty specimens and represent different type of dental composite. Furthermore, each main group was subdivided into three subgroups. Each one was composed of ten specimens which light cured with different light curing unit.

All the procedures of specimens' preparation were done at the room temperature of 25+_3°C under safe ambient light (from fluorescent ceiling source).

Three different light-activated resin composite materials of A2 shade were used for this study (Esthet X HD High Definition Micro Matrix Restorative, Dentsply Caulk, USA), (Spectrum TPH submicron hybrid composite Dentsply Caulk, USA), and (Z250 universal microhybrid composite, 3M Espe, America).

Before beginning the experiment, the light intensities were checked with Coltolux digital light meter. Time of irradiation (in seconds) of each curing mode was determined with the use of a digital timer and according manufacturers' instructions.

The depth of cure for each composite specimen was determined using the scraping method described in the 2000 ISO standard for polymer-based filling restorative and luting materials [11].

First we start by preparation of cylindrical specimens. A dark tube of polyethylene was used as a mold with a diameter of 6 mm and height of 8 mm. This tube was used as a mold for the composite specimens. The inner walls of the mold were painted with a mold-releasing agent (3% solution of polyvinylether wax in hexane). This solution didn't interfere with dental composite setting reaction and it is used to facilitate removal of the specimen from the mold after polymerization.

A transparent celluloid strip band had been placed on a flat glass slide on the top of a white filter paper and over it the end of mold tube placed and slightly overfilled with one increment of dental composite material being tested. A second transparent celluloid-strip was placed on other end of the mold and finger pressure was applied to the celluloid-strip to extrude excess material.

Ten samples were assigned for each curing mode and for each composite material. Before beginning the experiment, the light

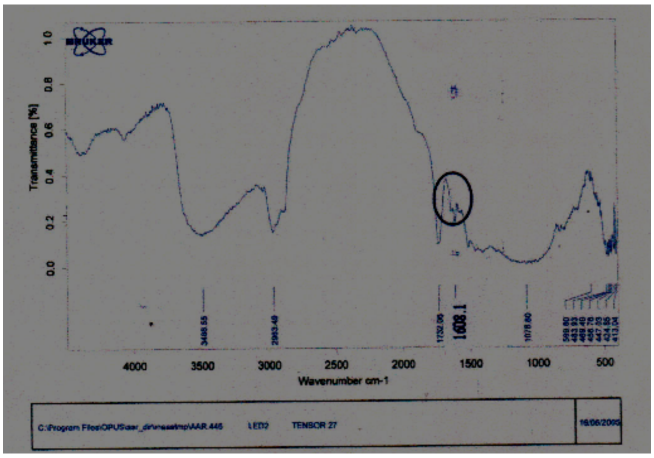

Figure 1: Exponential growth curves of the degree of conversion of dental composite with aliphatic and aromatic peaks [14].

intensities were checked with Coltolux digital light meter. The exit window of the curing light was placed over the cover slide (the light tip in contact with the celluloid-strip) and each composite material was irradiated, through the transparent celluloid strip, with the three different curing modes (Quartz-Tungsten halogen SDS Kerr, Danbury,CT , USA) , (light emitting diode Centrix, Shelton, CT, USA) &(Soft start light curing unit Degulux, Dentsply, USA).

The light curing units were used according to manufacturers' instructions.

1. 20 -seconds for (Quartz tungsten halogen).
2. 40 - seconds for (Light emitting diode).
3. 40 - seconds for (soft start light curing unit).

One hour after completing light curing, the composite specimens had been removed from the molds and the uncured material at the bottom of the samples were removed by scraping them away manually with a plastic spatula.

The height of the cylinder of cured material was measured with a digital caliper to an accuracy of 0.01 mm. This value was divided by two (in compliance with ISO CD4049: 2000, and recorded it as the depth of cure.

Means and standard deviations were calculated for group. The results were analyzed with two-way ANOVA and least significance difference test to find any significant differences between each pair of groups in regards to the depth of cure.

Degree of conversion assessment

Degree of conversion was determined by Fourier-transformed infrared spectrometry (Analect Instruments, Inc., Irvine, CA, USA) according to the standard baseline technique [12] (Figure1).

The samples used to evaluate the degree of conversion of composite resins were prepared by using a cylindrical fabricated aluminum split mold 6 mm in diameter and 2 mm in depth. The composite materials were condensed in this mold and confined by a glass slab from below and a celluloid strip on the top to allow direct contact of light curing unit tips with the strip. Then they were cured by the three different light curing units according to manufacturers' instructions for each type of the three curing units. Three samples of each type of composite resins materials were prepared. The total number for each material was nine samples. The samples were separated and stored in closed dark vials in an incubator for 24 hours at 37°C. After 24 hours, the samples were removed and separately grinned manually by a glass piston and mortar into a powder. The powder was mixed with potassium bromide by a weight percentage of 1:5 and the mixture was poured into a metal mold and compressed into a disc shape by the pressure device (press) at a load of 10 tons in order to make them ready for measurement by the Fourier transform infrared spectroscopy (FTIR).

The uncured controlled samples were prepared by devolving the uncured composite materials with carbon Quattro chloride (CCL4) which is an organic dissolvent and placed on a special cell supplied by the manufacturers of the Fourier transform infrared spectroscopy and become ready for measurement.

A thin film of uncured composite (30 μm) was formed between a potassium chloride crystal and a clean sheet of cellophane. The tip of the light unit was placed at a 45° angle to the surface of the crystal as close as possible to the dental composite without interfering with the infrared beam. During the 1st and 2nd min, spectra composed of 5 scans were acquired every 3 sec at a resolution of 4 cm^{-1}.

Photo activation, which had been triggered after the first spectrum, was obtained and this first spectrum was used as the uncured reference. In the 3rd and 4th min, spectra (also composed by co-addition of 5 scans) were obtained every 10 sec. For the last 6 min, spectra were obtained every 30 sec by the co-addition of 20 scans. The degree of conversion of each specimen was determined by comparison the ratio of the aliphatic carbon-carbon double bond(=), which has peak of absorption equal to (1640 cm^{-1}), with that of the aromatic component of cured and uncured states of dental composite materials which has peak of absorption equal to (1610 cm^{-1}) [13].

Three specimens were tested in each group. The constant of time reaction was calculated from the conversion curve. The time constant represents the time for the degree of conversion that reaches a value of 0.632 of its final value in the phenomena described by exponential growth curves [14].

By using the change in the ratio of the aliphatic to the aromatic

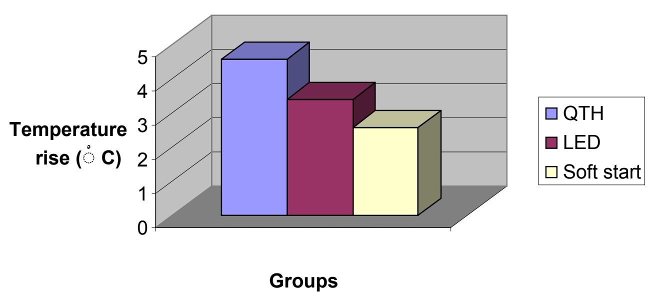

Figure 2: Temperature rise inside pulp chamber after curing of Z250 composite with different light curing system.

	Sum of Squares	df	Mean Square	F	P	Sig.
Between Groups	42.8	11	3.9	2.6	p<0.05	S
Within Groups	54.2	36	1.5			
Total	97.0	47				

Table 1: Two ways ANOVA test of the temperature rise inside pulp chamber after curing of Z250 composite with different light curing system.

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before and after curing, the degree of conversion could be calculated by using the formula:

1-(abs(aliphatic)/abs(aromatic))of polymer

Degree of conversion=--X 100

(*abs(aliphatic)/abs(aromatic))of monomer

* abs = absorption

Results

Temperature rise inside pulp chamber

Figure 2 represents means and standard deviations of the temperature rise inside pulp chamber after curing of Z250 composite with different light curing system. Quartz tungsten halogen showed the highest value for temperature rise (4.58) while Soft start had the lowest value (2.56).

The results indicate that the exposure induces minimal thermal changes at the level of the dental pulp chamber. With QTH light curing system the maximum temperature is always reached at the end of curing. The maximum temperature rise value which is (5.1°C) didn't reach to the lower border of the allowable temperature rise in the pulp chamber (5.6 °C).

ANOVA test in table 1 showed that there was an overall statistically significant differences in the temperature rise values inside pulp chamber among all groups of the curing systems (p<0.05) which include (QTH, LED and Soft start).

Results of the depth of cure

Means and standard deviations of the depth of cure, in mm ,of the Spectrum dental composite, which was cured with three light curing units (QTH, LED and Soft start), were showed in figure 3. Soft start gave the highest value of depth of cure (2.607) while Quartz tungsten halogen showed the lowest value (1.687).

Figure 4 represents means and standard deviations of the depth of cure of Esthet X dental composite which was cured with three light curing units (QTH, LED and Soft start). Soft start showed the highest value for depth of cure (2.877) while Quartz tungsten halogen had the lowest value (2.166).

Figure 5 represents means and standard deviations of the depth of cure of the Z250 dental composite which was cured with three light curing units (QTH, LED and Soft start). Soft start showed the highest value of depth of cure (2.557) while Quartz tungsten halogen had the lowest value (2.071).

ANOVA test in table 2 showed there were an overall statistically significant differences in the depth of cure values among groups of curing systems (QTH, LED and Soft start) and for different types of dental composites (Spectrum, Esthet X and Z250).

The least significant difference test showed statistically significant differences in the depth of cure values between QTH and Light emit diode, highly statistical significant differences between QTH and Soft

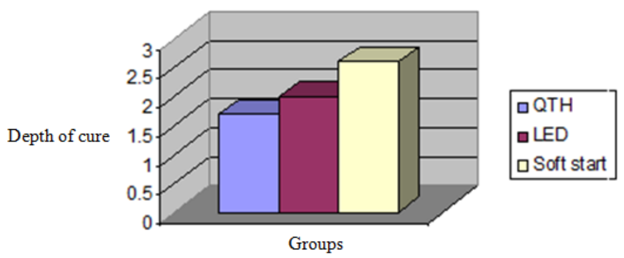

Figure 3: Depth of cure of Spectrum composite.

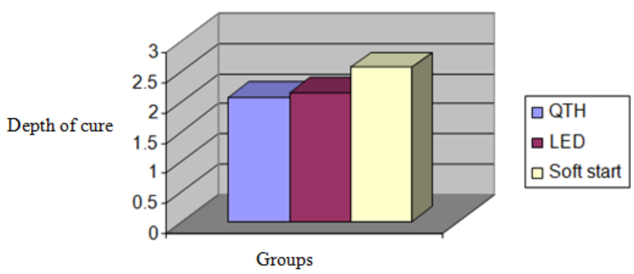

Figure 4: Depth of cure for Esthet X composit.

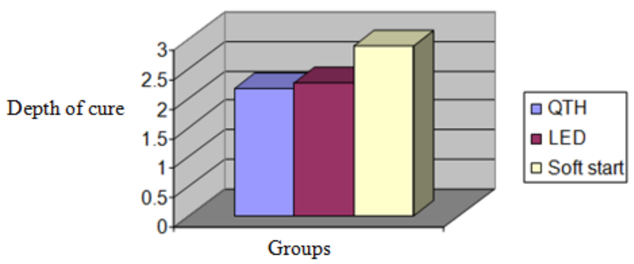

Figure 5: Depth of cure for Z250 composite.

Source	Sum of square	df	Mean square	F	P	Sig.
Between groups	23.34	11	2.12			
Within groups	233.46	108	2.16	0.98	p<0.05	S
Total	256.80	119				

Table 2: Two ways ANOVA test of the depth of cure of the different types of composite cured by different types of light curing systems.

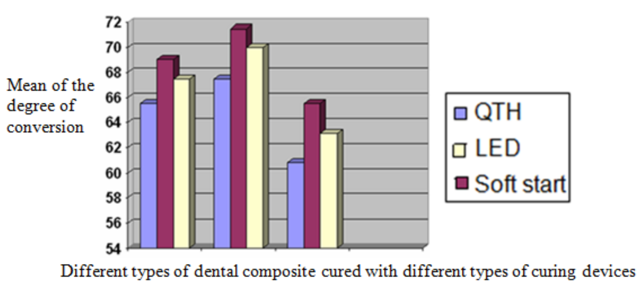

Figure 6: Mean of the degree of conversion of different types of dental composite cured with different types of curing devices.

	Sum of Squares	df	Mean Square	F	P	Sig.
Between Groups	264.534	8	33.067			
Within Groups	4.460	18	0.248	133.453		S
Total	268.994	26				

Table 3: Two ways ANOVA test of the degree of conversion of the different types of composite cured by different types of light curing systems.

start and between Soft start and Light emit diode when Spectrum dental composite was used. While there is no statistically significant differences in the depth of cure values between QTH and Light emit diode, highly statistical significant differences between QTH and Soft start and between Soft start and Light emit diode when Esthet X and Z250 dental composite was used.

There were statistically significant differences in the depth of cure values between Spectrum and Esthet X, highly statistical significant differences between Spectrum and Z250 and between Z250 and Esthet X when QTH light curing was used. While there were no statistically significant differences in the depth of cure values between Spectrum and Esthet X, highly statistical significant differences between Spectrum and Z250 and between Z250 and Esthet X when LED and Soft start light curing systems were used.

Degree of conversion

Figure 6 represents means and standard deviations of the degree of conversions of the Spectrum, Esthet X and Z250 dental composites which were cured with the three lights curing units (QTH, LED and Soft start). Esthet X showed the highest values of the degree of conversion among groups (67.5, 70 and 71.5) and Soft star had the highest degree of conversion (71.5). The lowest values were for Z250 (60.8, 63.16 and 65.5). QTH had the lowest value (60.8)

ANOVA test in table 3 showed that there were an overall statistically significant differences ($p<0.05$) in the degree of conversion values among curing systems (QTH, LED and Soft start) and for different types of dental composites (Spectrum, Esthet X and Z250).

When least significant difference test was used to compare the degree of conversion values of each pair of groups of dental composites and light cure systems. The result showed that there were highly significant differences between each two groups at a level of significance ($p<0.001$).

Discussion

Temperature rise inside pulp chamber

Light curing units used for polymerizing restorative resins produce heat during operation. Heat will be generated by the absorbed light as well as by chemical reaction of the polymerization process. Temperature increase during polymerization has to be taken into account [15].

Unfiltered IR can result in heat generation at the target site (pulp) [6]. Therefore to reduce the passage of IR energy from the source to the tooth, a thin heat absorbing filter is an essential component, then further filtered by a band pass filter.

As intensity of light activation unit and irradiation time, which are considered as variables governing heat generation, and the maximum pulp chamber temperature rise during resin-based composite polymerization show a linear increase with increasing light intensity [15] ,therefore, newer curing units with concentrating light guides or different light sources may require shorter curing times.

The result in this study is in corporation with the previous literatures mentioned above, in which they found that the higher rise in temperature was recorded with Quartz tungsten halogen then those which produce by light emit diode and finally Soft start light curing system.

But it is not incorporated with the results of Loney W and Price T [16], in which he reported that curing with the use of Quartz tungsten halogen did not cause higher rise in temperature when the curing time was for three seconds.

The mechanisms of Pulp injury include protoplasm coagulation, expansion of the liquid in the dentinal tubules and pulp with increased outward flow from the tubules, vascular injuries and tissue necrosis. It was reported that when external heat was applied to intact teeth, a 10 °F (5.6°C) rise in the temperature of the pulp caused 15% of the pulps tested to lose vitality, a 20°F (11.2°C) rise in the temperature caused 60% of the pulps to lose vitality, and a 30°F (16.8°C) rise in the temperature caused irreversible pulpal necrosis in 100 % of the pulps. Below 5.5°C, reversible and mild pulpitis occurred. Below 4°F (2.2°C), no histological changes were discernible [16].

The present study examined thermal changes in teeth following exposure to QTH, LED and Soft start light curing systems. The results indicate that the exposure induces minimal thermal changes at the level of the dental pulp chamber. The maximum temperature is always reached at or immediately after the end of light curing. This may be attributed to the thermal conductivity of the dentin, in that the thermal pulse dissipated within the tooth takes several seconds to reach the thermocouple.

The maximum temperature that it was permitted to reach may need even longer time in the mouth than those recorded in this study, due to cooling from pulpal blood flow and saliva. These same two factors would, similarly, be expected to reduce cooling times. Soft start light curing system is recommended strongly for curing dental composite because it provides the opportunity for cooling between exposures.

The results of the present study indicate that the highest temperature values which are 5.1°C for QTH, 3.6°C for LED and 2.8°C for Soft start were very low compared to the critical temperature increase which is 5.6°C, even though there is a statistically significant difference between the recorded temperature values of the three curing systems.

Therefore, it can be concluded that all modes and intensities which are used in this study are safe and will not affect the pulp tissue negatively. This result came in agreement with Chang and water-smith, [17] who reported that the use of low level energy for curing will be safe and the effect remain below the thermal critical threshold of pulp destruction.

Depth of cure: The ISO depth of cure (scraping) test used to determine depth of cure required minimal instrumentation and can be performed easily in a dental office. Using the curing light in their offices, dentists can readily adopt the ISO method to establish the depth of cure of various composite materials used in their practices.

Knowing the depth of cure of a particular shade of light-activated composite material would guide them in regard to the thickness of a composite layer that could be adequately cured clinically and provide them with a valuable baseline information about the specific depth of cure of different light-activated composite materials used by dentists. Once a baseline value is established, the dentist can use this method to check the depth of cure periodically to verify the performance of the resin-based composite and the curing light.

Although commercial light meters are available, they measure only the intensity of curing light. Resin-based composites can vary in composition, color and translucency, and curing-light intensity alone does not ensure adequate depth of cure. By using the ISO method to determine the depth of cure for a specific curing light and resin-based composite, dentists can obtain valuable information that can be applied clinically.

The ISO defined depth of cure as 50% of the length of the composite specimen after the uncured material is removed with a plastic spatula.

Although some researchers have used the total remaining length as the depth of cure after uncured material is removed, other studies have shown that, the hardness of the cured composite decreased significantly from the top of the specimen toward the bottom. If the total remaining length was used as the depth of cure, under polymerization likely would occur and clinical performance could be compromised [18].

ISO adopted a more conservative standard, defining the depth of cure as 50% of the remaining length. It was suggested that the depth of cure be defined as 55% of the remaining length of the scraped specimen [19].

DeWald and Ferracane [20] compared the scraped values with those obtained with double-bond conversion, hardness tests and translucency-changes as methods to determine depth of cure. Fan et al. [18] analyzed their data and concluded that, 50% of the scraped length results in similar or more conservative depth-of-cure values than those determined by the extent of double-bond conversion using infrared spectrometry or hardness. Therefore, the ISO method should ensure adequate polymerization of most resin-based composites [21].

In this study, each curing system and composite type significantly were affecting depth of cure, the effect of composite composition on the depth of cure is very obvious and this finding is in agreement with the finding of De Backer and Dermaut [22] who found that the most important factors affecting the polymerization depth are the composition and the physical properties of the composite resins and not the energy density. Esthet X light-activated composite exhibited the highest depth of cure values followed by Z250 .While Spectrum dental composite showed the lowest values of depth of cure.

Depth of cure of light activated resin-based composites is a function of the material's filler composition and resin chemistry, its shade and translucency, the intensity of the light source, and the length of the radiation exposure [23].

In this study, the shade was standardized for the three different types of composites (A2). The light intensity and exposure duration are converted into three different curing modes so that the variables in this study were only curing mode and composite type. The extent of polymerization is reduced at greater depth below the material's surface because of the lower intensities of light penetrating to this depth.

Depth of cure is affected by the size of the incorporated fillers. The filler particles in the resin-based composites scatter light. This scattering effect is increased as the particle size of the fillers in the composite approaches the wavelength of the activating light and will reduce the amount of light that is transmitted through the composite [20].

DeWald and Ferracane [20] found that, larger particle composites had the greatest depth of cure since they were least affected by light scattering. The small particles scatter light more than large particles, which make it harder for light to penetrate deep into the material.

The ratio of filler to unfilled resin matrix also is important. The data of this study came in agreement with the findings of Li et al. [24] in that a high filler concentration increases the depth of cure of composite material but it was disagree with the findings of Mills et al. [25] Who said that the higher the proportion of filler particles the more difficult it is for light to pass through the resin-based composites.

The data of this study is in agreement with the findings of Jain and Pershing [26] in that, the micro hybrid resin-based composite had the greatest depth of cure (in this study Esthet X and Z250 composites are micro-hybrids and both of them exhibited high depth of cure values). The findings of this study are not in agreement with the findings of Jain and Pershing, in that, greater irradiance (energy density) is needed to cure small particle resin-based composites in an attempt to increase their depth of cure because in this study the experimental light curing mode of high energy density did not greatly increase the depth of cure.

Degree of conversion: The FTIR has proved to be a powerful technique for the analysis of degree of monomer conversion in dental composite and in return to give an idea about the characteristics of the cured samples regarding their physical properties [27].

A remarkable event in this study is the initial low and final high intensities of Soft start light curing system which produces better results regarding the degree of conversion and the amount of residual monomer than other curing systems which are QTH and LED. This may be due to that initial curing with low energy of Soft start may give a better chance for dental composite to form more free radicals for further polymerization process and this give a better result of conversion from uncured composite with many free radicals to completely cure composite. While in case of QTH and LED the uncured composite directly exposed to final curing process without passing in the initial curing period.

In another ward, the Soft start system gives a rest period between a pre gel and post gel process and this will enhance the curing of dental composite and gives higher values of the degree of conversion. This explanation may interpret why Soft start light curing system showed the highest degree of conversion among other light curing systems.

This result could be explained as the influence of power density on the extent of conversion is already illustrated through its relationship to the polymerization rate. The increase or continues illumination time will lead to force the rate of free radical polymerization of acrylates and methacrylates to follow a characteristic pattern throughout the course of reaction due to diffusion limitation on the reacting species. This pattern is manifested early in the reaction by a decrease in the radical termination rate and a concurrent increase in the radical concentration. As a consequence, the rate of polymerization accelerates (auto acceleration) through a maximum despite a decreasing monomer concentration.

LED light curing system produced better results than conventional Quartz tungsten halogen light curing system regarding the degree of conversion. The reasonable explanation for this is that the halogen lamp is more efficient in the red and infrared light and is only slightly energetic in the zone of CQ absorption of maximum at 470 nm. It is common knowledge that red light produces more heat than violet light. Unfortunately, this means that the temperature rises without significantly improving photo polymerization. Important advantage of blue LED light curing system is the possibility to choose the most efficient wave length of 470 nm, justifying the very narrow wave length preference of CQ. Any wave lengths below about 430nm and above 500nm are not utilized in the electron promotion of the ketone groups in CQ and therefore it can be said that CQ ignores these wave lengths.

The unwanted wave lengths do produce additional heat affecting the kinetics of the reaction and may thereby influence the reaction. Conventional light sources produce a white light which is then filtered in an effort to remove the unwanted wave lengths.

The most efficient wave length for degree of polymerization conversion of resin when CQ used as initiator has been reported to be

470 nm. It was further shown by Nomoto et al. [28] that in the 450-490 nm wave length rang the degree of conversion is only weakly sensitive to wave length and the light intensity within this range is more important than the peak wave length. Outside this range, however, the wave length dependence is much stronger and the conversion rate drops rapidly. Temperature increase was influenced by higher energy density [29,30].

Conclusion

Under the circumstances of this *in vitro* study the following conclusions were drawn. QTH light curing showed the highest temperature rise value, while the soft start gave the lowest values. Soft start light curing revealed the highest depth of cure values, while the QTH showed the lowest value among three curing modes. There were overall statistical significant differences in the depth of cure values among groups of different curing systems and types of dental composites. Soft start light curing system showed the highest degree of conversion and QTH had the lowest values. Esthet X dental composite gave the highest results of the degree of conversion while Z250 showed the lowest values.

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